Generalised parametric functions and spatial correlations for seismic velocities in the Canterbury region based on dynamic site characterisation

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1. Background and objectives

This poster presents the development of generalised parametric functions to compute seismic velocities within the sedimentary deposits of the Canterbury region, with spatial correlations to represent the unexplained velocity variability in space. Previous studies characterised the 3D structure of geologic deposits throughout Canterbury for use in ground motion simulations and site response analysis but the velocity structure within these geologic formations are yet to be considered in detail.

This study makes use of the results of geophysical testing (passive and active source testing) at 23 sites throughout Christchurch city and the wider Canterbury region, as shown in Figure 1a. In the shallow near-surface (<200m), 18 sites shown are underlain by interbedded fine-grained sediments and gravels while the 5 remaining sites are predominantly gravel. Beneath these shallow interbedded layers lies the deep Tertiary layers.

Due to the dispersive nature of surface waves, dispersion curves for each site were generated and theoretical shear wave velocity (V_s) profiles were obtained through inversion. The inversion process was constrained using *a priori* geotechnical and geologic data to constrain the allowable velocity range and depths to geologic horizons – shown in Figure 1b. The median velocity profile of the 1000 lowest misfit profiles at each site was adopted for use in this analysis.

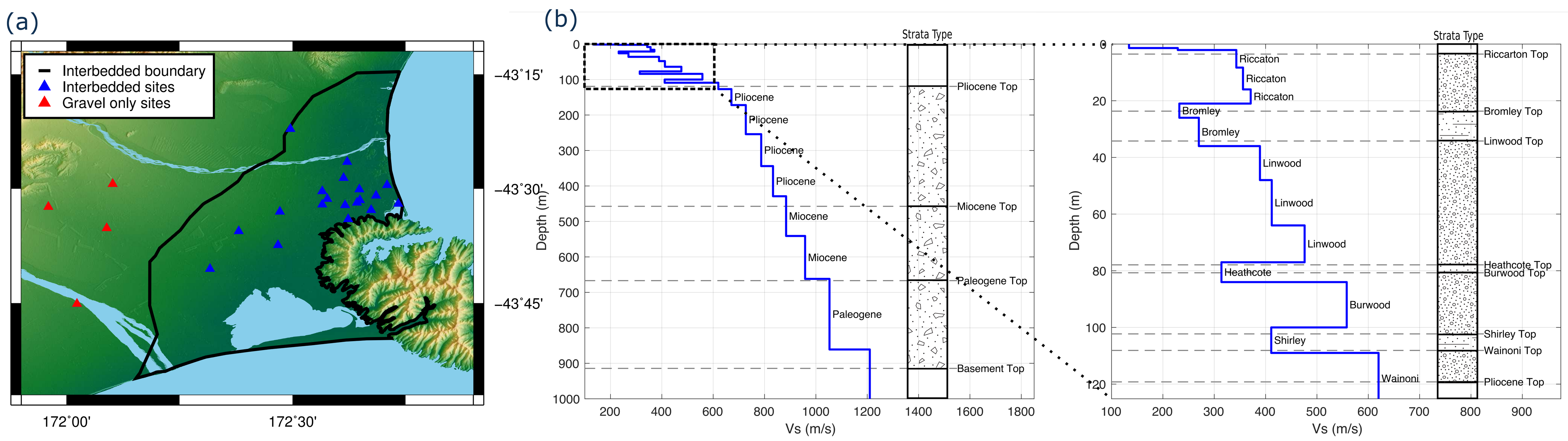

Figure 1: (a) Locations of geophysical testing sites in the Canterbury region highlighting the sites with interbedded Fine Grained Sediments and Gravels (sites with velocity reversals) and gravel only sites (monotonically increasing velocity with depth). (b) Median shear wave velocity profile for site LINC.

Figure 1b illustrates how layers of the median Vs profile are attributed to the different geologic layers. Considering all 23 sites, the layers were then separated according to type into three groups (Gravel, Fine Grained Sediment and Tertiary layers). Gravel layers (Riccarton, Linwood, Burwood and Wainoni); Fine Grained Sediment layers (Christchurch, Bromley, Heathcote and Shirley); and Tertiary layers (Pliocene, Miocene and Paleogene) were analyzed separately.

2. Depth dependency of Vs

Power models (functional form $V_s = aZ^b$) were adopted to incorporate the depth-dependence of shear wave velocity. Figure 2 illustrates the three power models for the three distinct layer groupings. Due to paucity of data it was not possible to develop power models for each unique geologic layer in Canterbury.

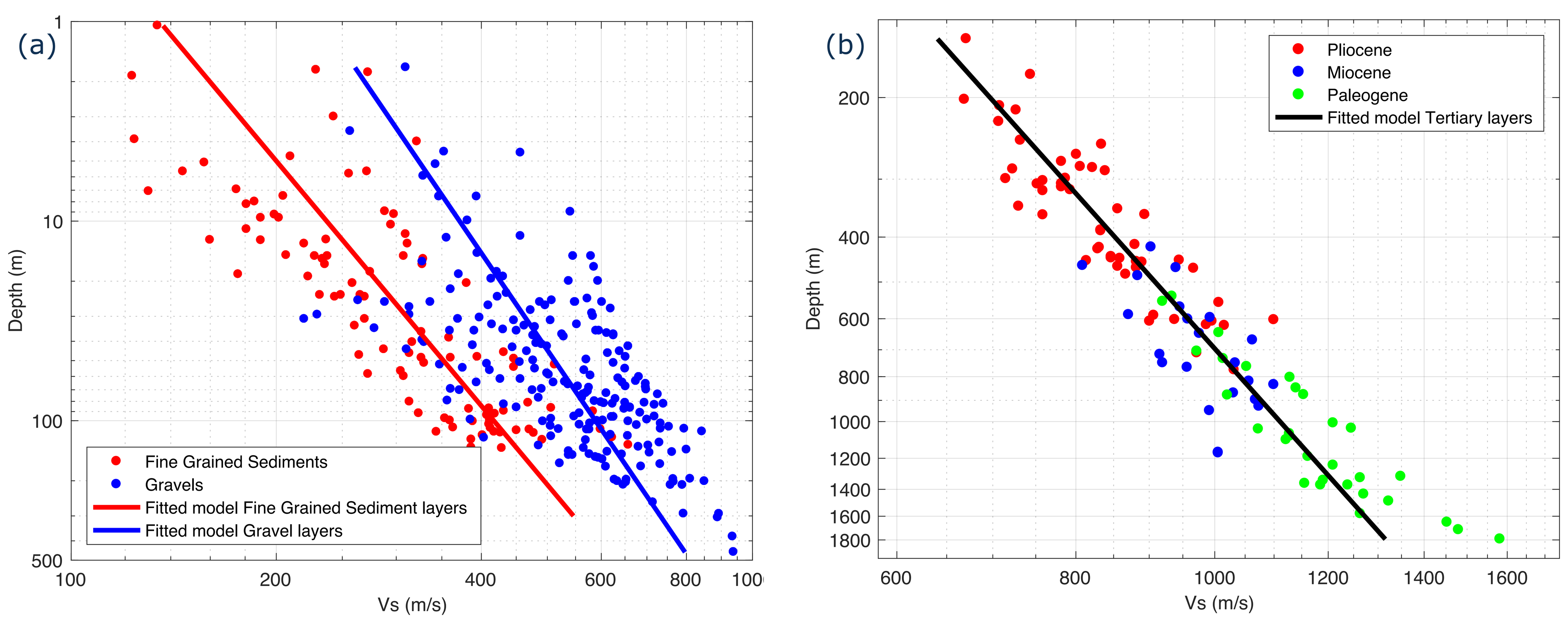

Figure 2: Fitted power models to prescribe shear wave velocity as a function of depth for: (a) shallow Fine-Grained Sediments and Gravels; and (b) deep Tertiary layers.

3. Semivariograms and geostatistical Kriging

From the fitted power models in Figure 2 a residual analysis was performed. The residuals for the shallow Fine-Grained Sediment and Gravels layers were investigated together as these layers are interbedded and inherently related. The within-site residual (δW_s - representing the residual between modelled and observed points on a V_s profile) and the between-site residual (δB_s – the mean of all within-site residuals at a site, representing the mean bias between the power model and all observations at a site).

Figure 3 presents empirical and theoretical exponential semivariograms for the between-site (in the horizontal direction) and the within-site residuals (in the vertical direction) for the shallow Fine Grained Sediment and Gravel layers, and the deep Tertiary layers.

- It can be seen that the variance for the shallow interbedded layers is significantly larger than the variance within the deeper Tertiary layers.
- The vertical lag distance (depth separation) at which velocities are no longer correlated is significantly smaller for the shallow interbedded layers than for the deep Tertiary layers. This is expected as the depth range for the shallow layers is ~200m while depth range for the deep layers is ~1km.

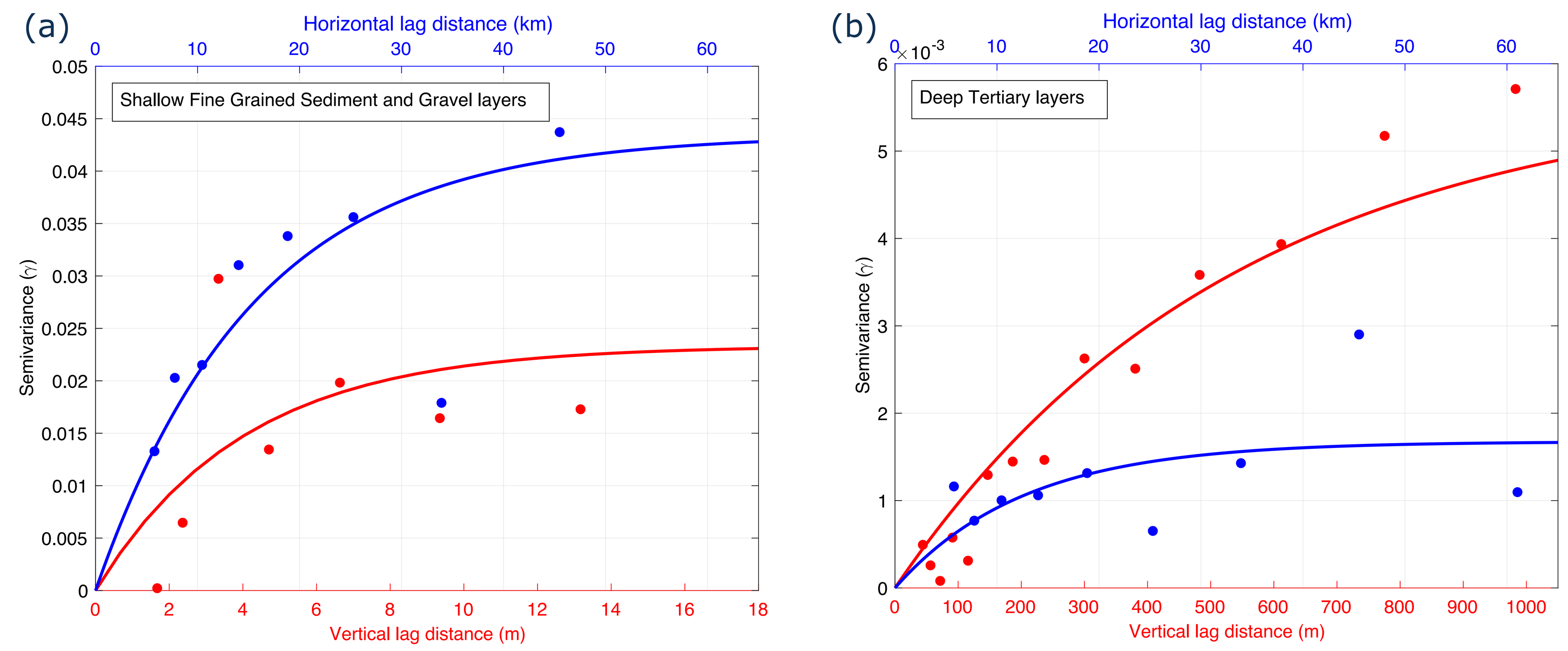

Figure 3: Semivariograms for between-site (blue) and the within-site residuals for: (a) the shallow Fine Grained Sediment and Gravel layers; and (b) deep Tertiary layers.

Using the Semivariograms in Figure 3, Kriging was applied to generate surfaces of spatial residuals for both the shallow and deep layers.

It can be seen that within Christchurch for both the shallow and deep layers that the between-site residual is negative, this is indicative of the power model providing an overestimate of the velocities in this region. Similarly in West Canterbury for the shallow layers the power model provides an underestimation of the velocities. The size of the between-site residual for the shallow layers is significantly larger than those of the deep layers.

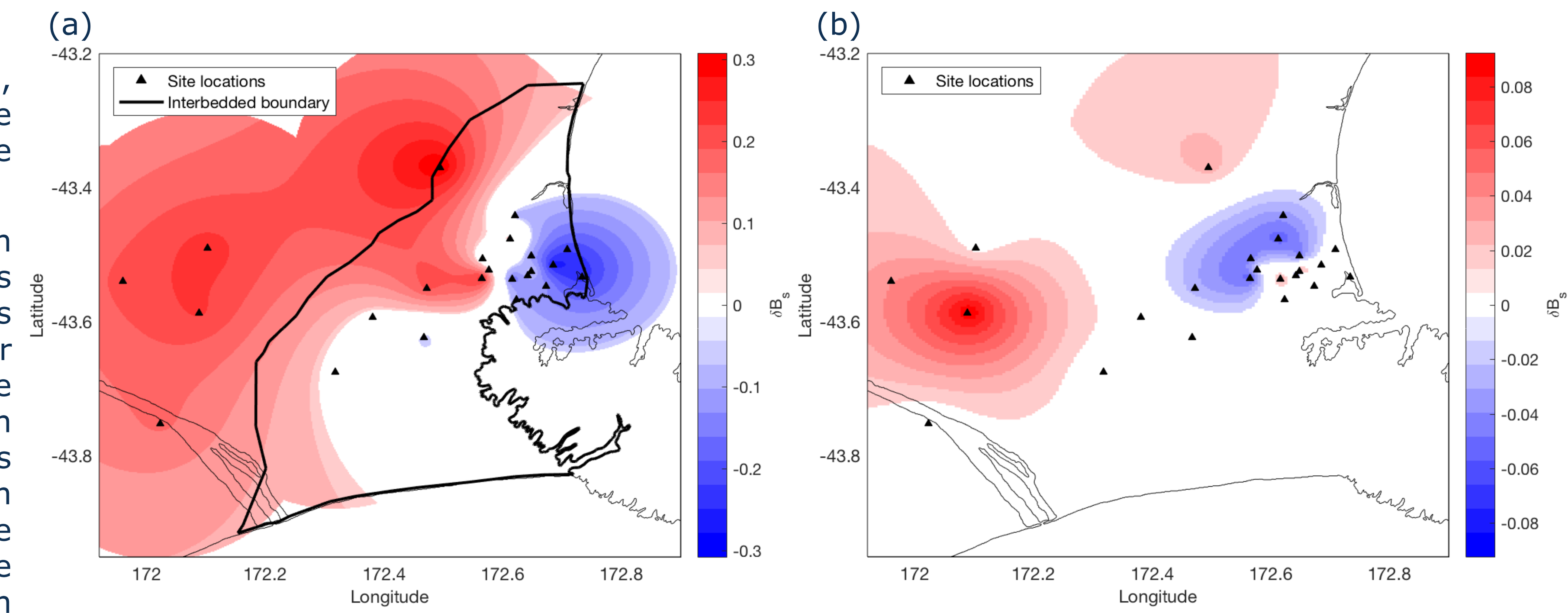

Figure 4: Kriged surfaces of between-site residuals for: (a) shallow interbedded layers; and (b) deep Tertiary layers

4. Generation of correlated Vs profiles

Using the semivariograms and spatial distributions of between site residuals, shear wave velocity profiles can be generated for locations throughout Canterbury using a multi-step process, illustrated in Figure 5:

1) Applying the baseline power models to each geologic layer
2) Interpolate to obtain spatial residual (site correction factor – the between site residual) at the site and correcting the baseline power model by this value
3) Generate a covariance matrix using the vertical semivariogram. Apply the covariance matrix to generate random correlated velocity perturbations with depth

The process can be extended to three dimensions by applying both horizontal and vertical semivariograms to generate the covariance matrix.

This process of using depth and spatial correlations to prescribe velocities within the geologic deposits of the Canterbury region represents a significant improvement on the way velocities within these formations are currently modelled. The methodology outlined here will be incorporated within the New Zealand Velocity Model (NZVM) for use in ground motion simulation and site response analysis.

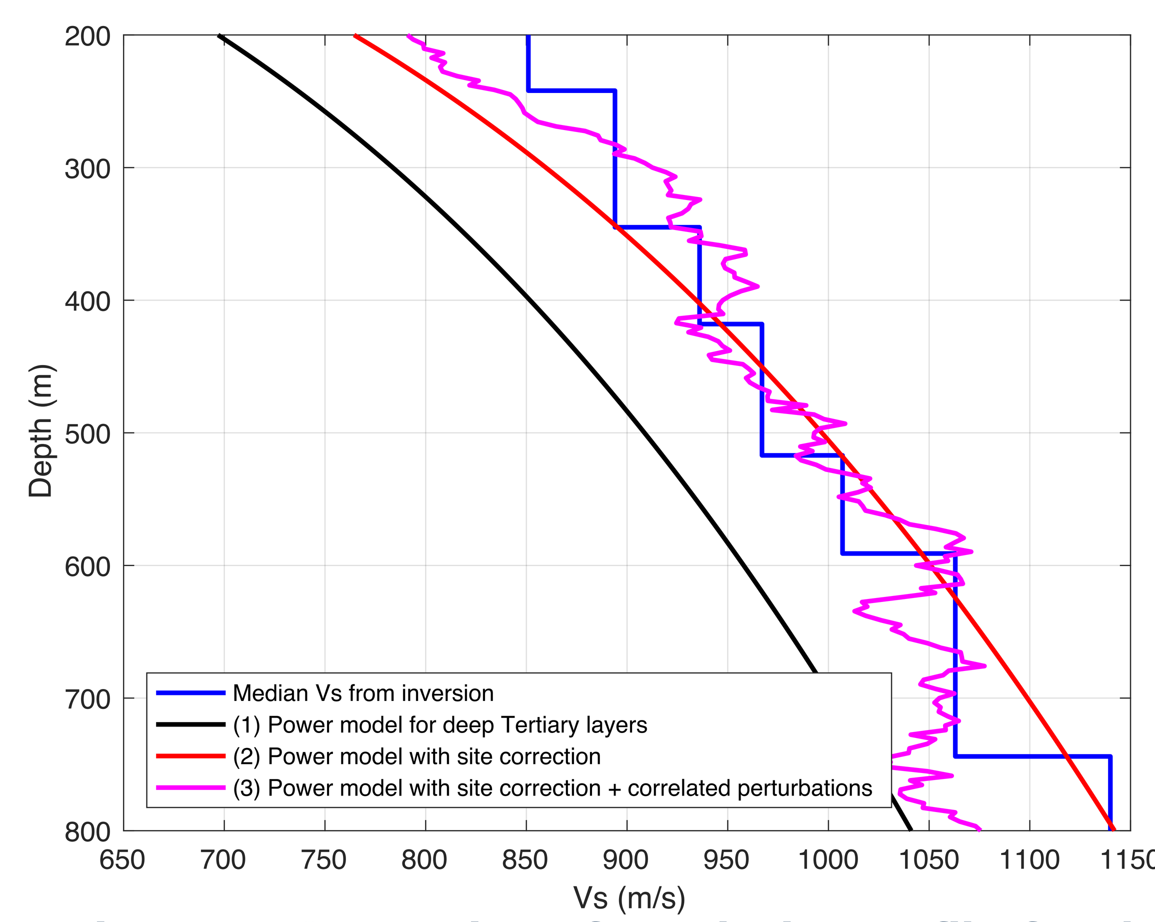

Figure 5: Generation of a velocity profile for the deep Tertiary layers at site GDLC with correlated velocity perturbations.